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Policy and regulation for smart grids in the United Kingdom

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ABSTRACT

The UK has adopted legal obligations concerning climate change which will place increased stresses on the current 'traditional' model of centralised generation. This will include the stimulation of large volumes of intermittent generation, more distributed generation and larger and more variable loads at grid extremities, potentially including large volumes of electric vehicles and heat pumps. Smarter grids have been mooted as a major potential contributor to the decarbonisation of electricity, through facilitation of reduced losses, greater system efficiency, enhanced flexibility to allow the system to deal with intermittent sources and a number of other benefits. This article considers the different policy elements of what will be required for energy delivery in the UK to become smarter, the challenges this presents, the extent to which these are currently under consideration and some of the changes that might be needed in the future.

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1. Introduction and aim of this review

Smarter electricity grids are widely considered to be an integral enabler of the transition to a low-carbon energy future both in the UK and elsewhere. This transition will pose significant challenges for electricity networks and their operators. They will have to accommodate new renewable generating technologies either as bulk connection to the transmission grid or as distributed but often remotely connected, and both with quite different characteristics from that of conventional generation. Systems must encourage and harness the contribution from more flexible consumption, while at the same time maintaining modern standards of security and reliability of supply. To meet these challenges, the future electricity system will need to be more integrated, smarter and flexible, employing sophisticated forms of monitoring and control to ensure that more diverse and variable forms of supply are matched with more flexible demand on a continuous basis.

Against this background, the level of interest and activity related to the development of smarter electricity systems continues to grow. The UK has begun to make significant changes at the system level to encourage not just the new technologies that will drive demand for smarter energy delivery but also to enable various stakeholders to respond. The UK Government's Department of Energy and Climate Change (DECC) and the UK's energy regulator, Ofgem, are in the process of radically changing the market environment for electricity (including renewable electricity) and the way network investment and operation is incentivised. They are also considering what other coordination might be needed to drive the development of smarter energy solutions and to this end have begun to consider enhanced regulation of innovation, stakeholder networks and other new approaches which might alter the approach to electrical delivery in the future.

Although there is worldwide interest in the development of smarter energy delivery, an ambitious decarbonisation agenda together with the liberalised nature of the UK electricity system makes for a particularly interesting study in terms of smart grid deployment. The need to ensure that regulated network companies are incentivised to innovate and drive the deployment of smart grids in a cost-effective fashion is paramount and the initial steps taken to evolve UK network regulation in this respect are particularly interesting.

Smart grids currently enjoy a prominent place in the technology and energy literature and practice. We draw on a variety of relevant academic and policy sources to review the current regulatory framework of the UK electricity supply industry (ESI) as it relates to smart grid development, setting out the policy drivers that underlie the need for smart grid development and the limited smart grid related initiatives already under way. We discuss some of the underlying issues relating to the current regulation of the ESI and the potential for conflict between these and the way that grid investment and market operation will need to operate as anticipated policy-driven generation and consumption changes take hold. The review will outline the current state of policy specific to smart grids and smart metering. It will discuss the barriers to the changes that the UK wishes to bring to the ESI and to the adoption of smart grids as a partial solution to some of the challenges thrown up by the necessary evolution of the UK ESI. The evolution of the UK ESI has already begun in some significant regards, with changes to both the market incentives for generation and to the regulatory incentives for decision concerning investment in the transmission and distribution networks. This review discusses the changes that have already been made and their implications as well as their limits. Further to this, we consider the need for changes to be introduced to enable the solutions that are increasingly likely to be required for smart grid deployment.

1.1. A working definition of 'Smart Grid'

There is no globally agreed upon definition of a smart grid [1]. The International Electrotechnical Commission states that "the Smart Grid is the concept of modernising the electric grid […] the main focus is on an increased observability and controllability of the power grid" [2]. US definitions of smart grids tend to focus more on energy system resilience and reliability [1]. Smart grids have also been defined in terms of a broader range of social, environmental and economic features and functions [3]. For the purposes of this paper, we adopt the more flexible Smart Grids European Technology Platform definition of smart grids as "electricity networks that can intelligently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies" [4].

1.2. The role of supporting organisations for smart grid implementation

DECC is the UK Government department responsible for UK smart grid policy. Ofgem has oversight of the utilities responsible for electrical delivery, protection of the general interests of energy consumers and for providing the incentives to shape the sector to meet the UK's energy needs. As such, they strongly shape the direction of the sector. A number of other organisations are active in relation to smart grids in the UK, representing different stakeholders. The most active in the policy process are considered here.

1.2.1. The Electricity Network Strategy Group (ENSG)

The ENSG is a high-level stakeholder consultation group facilitated by DECC and Ofgem to bring together energy companies, trade associations and the devolved administrations. Broadly, ENSG's aim is to identify and co-ordinate work which addresses the key strategic issues likely to affect the electricity networks in the transition to a low-carbon future. It can be regarded as contributing to uncovering some of the key issues that will impact smart grid development and to initiating debate over how the sector might address them [5].

1.2.2. The Smart Grid Forum (SGF)

DECC and Ofgem jointly facilitate the SGF, extending the ENSG's work, and the influence of the ENSG can be seen in the joint DECC/Ofgem 2014 document “Smart Grid Vision and Routemap” [6]. SGF's brief is to identify the challenges and barriers to the adoption of smarter electricity networks, provide guidance to DECC and Ofgem as to identifying and overcoming these and work with stakeholders to facilitate deployment. SGF members are supposedly selected as individuals rather than as representatives of their organisations, but most are attached to energy companies along with representatives of three industry associations, Government and Ofgem representatives, an academic and an NGO. There is no consumer representation.

The SGF intends to engage stakeholders via multiple work streams [7,8]. The work streams will run on an overlapping basis “to address commercial and cultural as well as technical changes and the barriers the network companies face in making these changes”. The SGF has published a network model (2012) that allows DNOs and developers to carry out cost benefit analysis of smart and conventional solutions to network problems. The model, which is licensable and updateable, will allow industry and policymakers to test the value of new developments in specific circumstances and aims to assist DNOs in the development of business plans and Ofgem as regards the RIIO ED1 price control process.

The SGF will continue to identify network challenges and solutions in the move to low carbon energy delivery, particularly in relation to distributed generation, the electrification of heating and transport, smart metering and active network management. It will continue to consult with sector stakeholders regarding the content and goals of the work streams; some have already been carried out. The Electricity Market Reform (EMR) White Paper makes it clear that the SGF will lead in developing government strategy relating to smart grids, in establishing shared assumptions with the involved utilities and to address future challenges regarding the electricity network [9].

Stakeholder interviews suggest that the establishment of the SGF is largely seen as a very positive development in terms of the opportunity for key stakeholder representatives to come together. The DNOs particularly have been represented by senior personnel; this was regarded by commentators as a direct response to the greater influence of suppliers in the initial stages of planning of the smart meter rollout, a development where the DNOs were generally held to have been slow to respond, particularly given its implications for their future business. This can be linked directly to the problems of the broken value chain noted in Section 2.7. This also supports the idea that the SGF is perceived as being able to positively influence government decision on smart grids.

Stakeholders emphasised there is much more to be done to ensure the level of coordination that many felt was essential to ensuring circumstances were right to allow the capture of an optimal set of benefits arising from smarter energy delivery. The Government was seen by many stakeholders as having more to do in the role of coordinator.

1.2.3. SmartGrid GB

The UK Government and the SGF have agreed to work with SmartGrid GB, a new industry-led initiative which has emerged with the goal of increasing understanding of what will comprise a smart grid, and the challenges and benefits of moving towards smart energy delivery, to drive forward adoption of smart grids and to facilitate action amongst stakeholders. Its members are drawn from multiple sectors, including energy utilities, ICT providers and others such as Consumer Focus with an interest in different elements that will inform future smart grids development in the UK [10]. SG-GB is also lobbying for the capture of economic opportunities likely to emerge from a systemic move to smarter energy delivery, including both cost saving and industrial development, which may emerge from early investment. They calculate that early movement on developing and installing smart energy technologies might reduce required investment in UK distribution networks by 2050 from £46bn to £23bn–£27bn. Further, they suggest smarter network management technologies might save up to £10bn even if the uptake of low carbon technologies remains low. This would tend to mitigate the risk of early movement, which they suggest would imply an extra cost of less than £1bn. Their report also notes that there would be significant benefits, or alternatively opportunity costs, in secondary industries related to low carbon, including electric vehicles, and the delivery of renewable heat and renewable electricity. The report also predicts the creation of up to 9000 new jobs by 2020 stemming from the overall economic stimulus, declining to around 5000 jobs by 2040 [11].

1.2.4. Trade associations

A number of industry stakeholders are active in the UK policy landscape as regards smart grids.

The Electricity Networks Association (ENA) represents transmission and distribution companies in the electricity and gas sectors. They have supported the publication of a number of reports concerning smart metering and smart grid development in the UK, sometimes in partnership with the SGF and with Energy UK [12,13].

Energy UK is a trade body representing the UK energy sector, including companies working in electricity generation, energy networks and gas and electricity supply as well as equipment providers. They have produced a number of publications concerning smart metering and demand response issues in the UK, and the need to get both right.

The British Electrotechnical and Allied Manufacturer's Association (BEAMA) describes itself as an independent expert knowledge base and forum for the UK electrotechnical industry. It aims to influence the political, regulatory and standardisation framework which shapes the electrotechnical sector. As with SG-GB, BEAMA is keen to make a case for the UK to focus on the direct and indirect benefits of smart grids, that is, both the cost savings and potential to stimulate innovation and thus new technologies and services [14].

1.2.5. Consumer Focus

Consumer Focus (CF) has a legally mandated consumer protection role concerning energy supply in the UK which includes consideration of any issues arising from the development of smart grids.

Responsibility for consumer representation, complaint resolution, information provision related to the UK ESI were absorbed into CF in October 2008, funded by the Department of Business, Innovation and Skills (BIS) and by utility licence fees. They were given significant statutory powers relating to consumer representation including “the right to investigate any consumer complaint if they are of wider interest, the right to open up information from providers, the power to conduct research and the ability to make an official super-complaint about failing services.” However, following the UK's 2010 change of Government, Consumer Focus is being abolished, and from spring 2013 these powers are located with the Regulated Industries Unit (RIU), which will transition to another organisation, Citizens Advice. It is not clear how this will impact consumer representation on issues where development of new technologies and applications may imply significant impact on consumers, as with medium and long-term rolling out of smart meters and smarter grid technology.

1.3. Policy drivers for smart grids

UK and European policy interest in smart grid technologies is based on their potential to contribute to policy goals of a transition to a low-carbon economy, energy security and affordability by transforming the ways we produce, deliver and consume energy, and potentially our conception of these services. Smart grids are able to provide better planning and management of existing and future electricity distribution and transmission grids; actively manage supply and demand; and enable new energy services and energy efficiency improvements [15]. Current research into these transformations [3,16,17] indicates a decarbonisation of energy supply, increasing distributed generation and potential electrification of transport and residential heating, potentially with demand side response strategies and storage technologies to help address intermittency and peak-load constraints, might all be managed more efficiently by smart grids.

The UK has a legally mandated policy goal of an 80% reduction in national climate change emissions by 2050. It also has a legal obligation under EU law to generate 15% of all energy consumption from renewable energy sources by 2020 [18,19]. Key to achieving this is meeting an ambitious target specific to renewable energy sources of electricity (RES-E). DECC's Renewable Energy Roadmap requires around 30% of electricity come from renewable energy sources if there is to be any chance of achieving the goal. This represents a significant increase from the 10.8% of electricity that was sourced from RES-E in 2012 [20]. DECC's expectation is that the majority of this additional RES-E capacity will come from onshore and offshore wind and from biomass combustion [21]. Fig. 1 presents government projections for the increase in renewable energy capacity to meet the 2020 targets. Pressure beyond that may mean the percentage of renewables needs to keep rising. Fig. 2 clarifies the fraction of the total which the government projects will be from RES-E by 2030 [22].

While biomass-based electrical generation is predictable, wind is more intermittent in nature and conventional generation will in future be required to meet a demand profile net of renewable output – a profile that will be far more volatile and unpredictable than is currently the case. Conventional generation will experience a reducing and more unpredictable utilisation as renewable output builds and there are concerns over the ability of current market arrangements to deal with this volume of intermittent generation capacity and provide sufficient incentives to keep the conventional capacity required to maintain security of supply. Furthermore, the addition of large volumes of new capacity is likely to be in locations which do not currently have sufficient grid capacity to deal with its connection, and this is in addition to the need for expenditure of ageing elements of the UK ESI. There is concern that the current system of price signals may not provide sufficient incentives for the necessary investment in either the transmission or distribution networks. Ofgem's Project Discovery outlines five key areas which represent key challenges for UK energy supply [23]:

- There is a need for unprecedented levels of investment to be sustained over many years in difficult financial conditions and against a background of increased risk and uncertainty. Project Discovery suggested that the requirement for investment might be as high as £200bn up to 2020 if environmental and other goals were to be met, suggesting a rate of investment twice as great as the typical rate to 2010. A figure of £32bn has been estimated for the required enhancements of the electricity and gas networks, a figure which represents around 75% of the total value of the networks currently [23,24].
- Uncertainty in future carbon prices is likely to delay or deter investment in low carbon technology and lead to greater decarbonisation costs in the future.

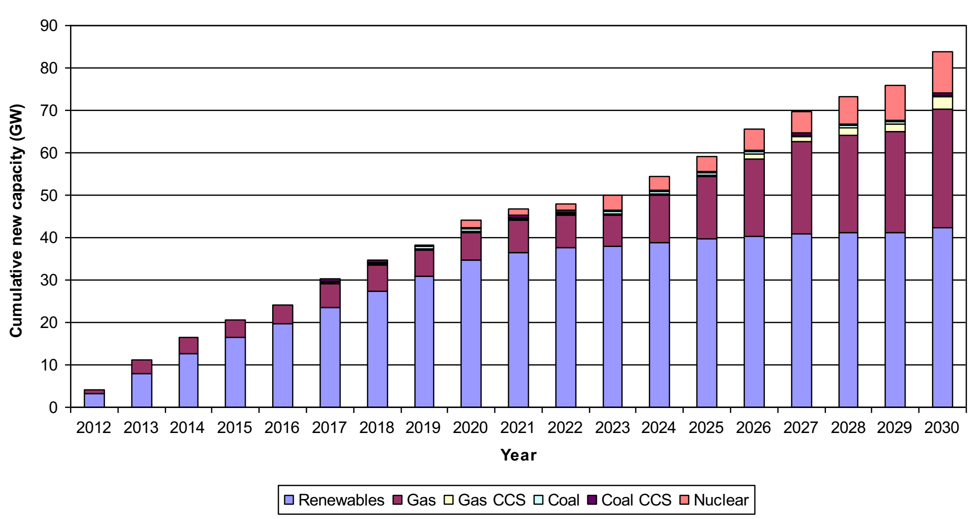

Fig. 1. Cumulative growth in new build capacity by technology. [22].

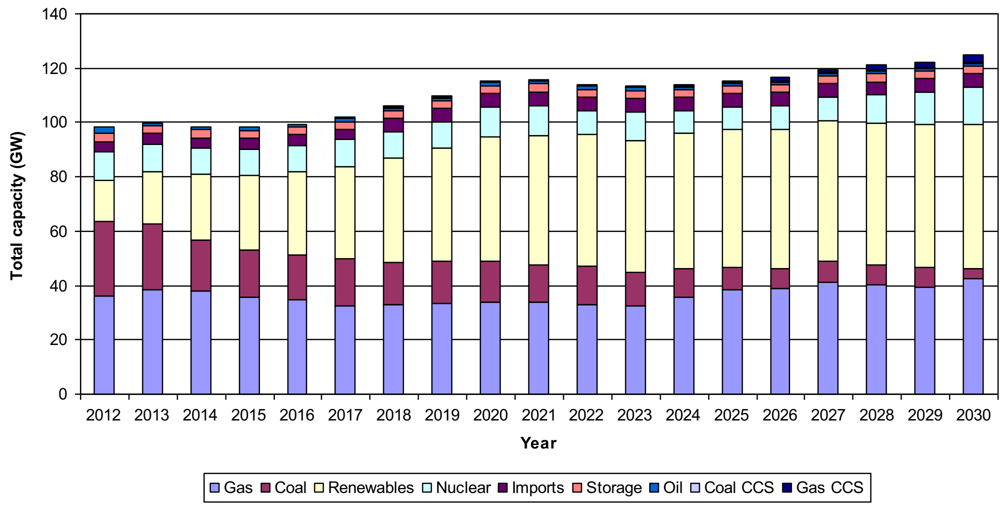

Fig. 2. Total projected installed UK electrical capacity by technology, 2012–2030 [22].

- Short-term price signals at times of system stress do not fully reflect the value customers place on supply security which may imply a requirement for stronger incentives to make additional peak energy supplies available and to invest in peaking capacity.
- Interdependence with international markets exposes GB to a range of security of supply risks.
- Higher gas and electricity costs may mean that increasing numbers of consumers are unable to afford sufficient energy to meet their requirements and that the competitiveness of industry and business is affected.

Change will need to occur in the context of an energy system which will see up to a quarter of existing electrical generating capacity close down as nuclear and coal power stations reach the end of the operational life. The UK is thus faced with developing policy which will address challenging environmental and security of supply issues, whilst controlling the economic costs of their response such that access to energy for both domestic and commercial consumers is manageable. This will require changes in how energy markets operate, how networks are regulated and incentivised, how consumer demand is managed (and how consumers manage their own demand) and in how investment in meeting these challenges can be incentivised. There is no doubt that substantial direct investment as well as investment in infrastructure will be required.

Thus the development and evolution of effective smart grids and the achievement of the goals associated with smart grids will require significant changes in multiple areas of electricity delivery and consumption. It will necessitate changes in the motivations and behaviour of multiple existing stakeholders including policymakers, regulated and competitive utilities, investors, consumers and regulators, as well as changes which will encourage new entrants to the energy sector and encourage innovation in technology, service provision, grid and other management by both established and new stakeholders. The degree of change that will be tolerated by stakeholders will shape the political acceptability of the degree to which smart grids evolve and are adopted. Policymakers may respond to the need for change to different degrees and will be influenced by the potential for cost and carbon savings, the opinion of other key stakeholders and the representation of the issues which emerge from the press in the wider context of public opinion.

The UK Government and GB energy regulator, Ofgem, have acknowledged the need for change in the policy and regulatory framework and begun the process of changing key elements of the system. These changes will reform the electricity market, change the incentives for key stakeholders and create instruments which will directly impact the shape of smart grids, the services that can be made available using smart grids and smart technologies. They will have the potential to complement or block increasingly smart networks and drive forward the achievement of policy goals which will make a greater case for the economic and technological benefits that smart grids might bring.

The key elements of the current governance response to the anticipated changes in electricity supply manifest through two key instruments: the Electricity Market Reform (EMR) and the regulatory shift from RPI-X to RIIO. In addition, the roll-out of smart metering has prompted Ofgem to initiate a work programme to deliver a smarter electricity market over the longer term [25,26], while Ofgem's review of cash-out arrangements[1] could also have a significant impact on UK electricity market design [27]. On a European scale, the development of a single integrated electricity market by 2014 through the harmonisation of Member State trading arrangements and market rules will also have a significant impact on GB electricity market design.

EMR is a move rooted in primary legislation and driven by the Government while RIIO will change the regulatory incentives for network operation. Both will transform the incentives and it is hoped this in turn will change the behaviours of investors and other stakeholders, will allow greater flexibility in the electricity system and may make targets easier and more cost effective to achieve. Both will attempt to drive innovation in environmental technologies and it is hoped the smart grid technologies will enable them. Along with other policy initiatives they are intended to drive the changes needed for the UK to meet its sustainability goals, to ensure security and reliability of supply and to achieve both goals while limiting costs to both commercial and domestic consumers.

A shift to smarter grids, with smart meters and smarter market design, is seen as key to accommodating innovation in environmental technologies and energy services, managing costs through increased consumer participation and ensuring an increased demand side contribution, while at the same time widening consumer choice and improving consumer understanding and management of their consumption.

[1] Cash-out arrangements; the arrangements whereby imbalances between a market participant's contractual position at market closure and actual outturn are cashed out ex-post.

2. Policy instruments to drive up the value of smart grids

The UK currently has two key financial support instruments to support the growth of RES-E; the more significant of these will be slowly replaced within the context of the EMR up to 2017. Additional mechanisms support growth in renewable energy sources of heat (RES-H); successful stimulation of RES-H will also have electrical network impacts, which may prove an additional challenge to network managers.

The mechanisms detailed below are the major instruments aimed directly at stimulating renewable energy technologies; other policy instruments such as the Climate Change Levy (CCL) and Energy Companies Obligation (ECO) will also have impacts as part of their general goal of reducing emissions.

2.1. The Renewables Obligation

The Renewables Obligation (RO) is currently the central mechanism for supporting the growth of large-scale RES-E in the UK. It is a quota mechanism which creates demand for RES-E amongst supply companies by compelling them to either purchase RES-E from RE generators or pay a penalty for each unit by which it falls short [28,29].

The RO represents a substantial financial stimulus and has driven RES-E from 4.5% of energy consumption in 2006 to 10.8% in 2012 [20]. It has so far largely driven onshore and offshore wind and biomass combustion for electrical generation. The UK Renewable Energy Roadmap predicts that wave, tidal, ground and air source heat pumps, biomass combustion for heat may see limited expansion up to 2020 and accelerate beyond that, while other technologies may also make contributions. Solar PV has historically been supported by the Micro-generation Tariff as projects tended to be under 5 MW in capacity, although larger projects are not emerging that may draw on ROCs or the CfD below. The greater part of the expansion of onshore wind is likely to be in Scotland. Extensive rounds of offshore wind expansion are likely to be centred on sites in the Moray Firth, Firth of Forth, North Sea, the Irish Sea and then in limited locations in the English Channel and Bristol Channel. This will require considerable investment in transmission and distribution network expansion as well as presenting challenges in terms of the management of large volumes of intermittent generation [30].

While the RO has driven some growth in RES-E, it has been compared negatively with tariff applied in many EU Member States and will be phased out between 2013 and 2017 in favour of Contracts for Difference (see below), a tariff like financial instrument that is being introduced as part of the Electricity Market Reform (see Section 2.6). [9].

2.2. Feed-in tariffs for microgeneration

Introduced in April 2010, feed-in tariffs provide a fixed payment for generation from RES-E plant under 5 MW. The scope is much less than that of the RO but this holds the potential for making millions of small consumers into consumer-generators. This will add levels of complexity to managing distribution networks right down the micro-grid level and may require some of the technical solutions that classify as smart grids. The feed-in tariffs have been subject to a number of modifications since their introduction and are currently under review as concern arose about the level of payments in comparison to rapidly falling prices in specific small-scale RES-E technologies [31].

The tariffs can be credited with driving the rapid deployment of PV in the UK, pushing up installed capacity to 2.4 GW by June 2013, from a very low base [32].

2.3. Renewable Heat Incentive

The UK is in the process of introducing a pioneering policy instrument to financially support renewable energy sources of heat [33]. The Renewable Heat Incentive (RHI) will provide a fixed tariff per unit of heat energy produced from eligible technologies [34]. The key technologies likely to be stimulated are biomass boilers, ground source heat pumps and solar thermal. Air source heat pumps may also contribute to UK RES-H generation, but are not yet included in the RHI [30].

The RHI is potentially significant in terms of future UK smart grids. The most important is that several scenarios suggest the possibility of large-scale uptake of heat pumps, pushing up electricity demand relating to heat in commercial and domestic properties. The RHI will be at the forefront of the initial expansion of heat pumps. The expansion in the adoption of heat pumps also presents some danger of an increase in electricity use for cooling in the domestic sector, if installation of reverse cycle heat pump systems leads to comfort taking by consumers who would not previously have had access to cooling [35].

The RHI will also change the economics of biomass CHP systems, potentially increasing the volume of new capacity in this area, and adding to the number of small distributed electrical generators active in the UK [35].

2.4. Zero carbon homes and non-domestic buildings

The UK has adopted policy to reduce the emissions related to climate change that are associated with energy use in new homes and other buildings [36–38]. While the proposals were diluted to some extent by the new UK Government in 2011 [39] they have the potential to drive up the use of renewable energy systems since matching installed renewable energy against energy demand in the building earns credits to raise the carbon rating of the building.

2.5. Electrification of transport and heat

The UK Government's short-term plans for reducing emissions from transport are focussed on regulating a minimum fraction of road vehicle fuel to come from biofuels; this is unlikely to impact the ESI. However, a number of scenarios for long-term reduction of emissions from transport fuel are rooted in the electrification of transport [21,40].

At present, a number of factors are slowing down the development of EV value chains, including the lack of a clear regulatory framework and initiatives and the absence of significant customer demand [41]. The current policy instruments in place to support electrification of transport in the UK include:

- 'Plugged in Places', a Department for Transport project funding early stage infrastructure in eight urban centres.
- A grant of 25% (to a maximum of £5000), on electric car purchases, with 3633 grants approved by the end of March 2013. A grant of up to 20% (to a maximum of £8000) for EV and PHEV commercial vehicles of 3.5 t. As of 31 March 2013, 264 claims had been made [42].
- A fund of £37million to support a network of recharging points.

Future EV numbers are difficult to predict and forecasts vary from 1% to 10% of cars in the UK by 2020, with a massive range from around 100,000 to 1.5 million, with challenges for the grid manifesting after that year [43]. Many of the scenarios that predict this electrification of transport also predict a shift to greater use of electrical energy for heating purposes, albeit through the use of heat pumps rather than direct application in space and water

heating. The UK Government Routemap for Smart Grid Development notes a range of projections for heat pump uptake varying between around 1 to 7.5 million by 2030 and for EV uptake of up to 10 million units by the same year [6].

These predicted shifts would impact significantly both overall demand and peak demand and additionally would impact resilience of local grid networks significantly, thereby increasing the complexity of their management. The expected shift could double the peak demand and substantially drive up total electricity demand. Smarter grid and network management, combined with enhanced capacity for demand response (DR), could offer substantial value in addressing the demands that this would place on the network, without requiring a doubling in available capacity to meet the peak demand. Aghaei et al. note the potential of DR to bring a number of systemic benefits, including as regards pricing, cost effectiveness, reduction in environmental impacts and availability of new consumer services [21,35,40,44].

2.6. Electricity Market Reform

The Electricity Market Reform (EMR) is the government's policy and legislative initiative aimed at putting in place a number of instruments that will support the UK in meeting its environmental goals, while providing incentives for a new plant to maintain capacity margins and provide the firm capacity required to underpin greater levels of those RES-E technologies which generate intermittently and potentially significant variations in the large-scale use of heat pumps or electric vehicles.

The government aims to run consultations through 2012 and initiate legislation in the latter part of that year with an aim of providing support from 2013. The core initiatives presented in the EMR are described below.

2.6.1. Contracts for Difference

The Feed-in Tariff with Contracts for Difference (FiT-CfD or just CfD) was announced as part of the EMR in July 2011 [9]. CfD will replace the RO as the mechanism for providing finance to support the development of large-scale RES-E in the UK and represent a significant change in the approach to funding in this area. However, the key RES-E technologies supported under CfD are likely to remain the same as under the RO, and largely present the same challenges. The CfD will be introduced from April 2013 and the RO will cease to accept RES-E generators for accreditation from March 31st 2017. All RES-E generators will have a one-off option to stay with the RO or move to the CfD before 2017. It is not yet clear how the RO will operate once some generators elect to withdraw [9].

The CfD mechanism, as currently proposed to apply to RES-E, is somewhat different from the typical FIT employed in many EU Member States. The CfD system will see a contract between a RES-E generator and a contracting counterparty. RES-E trading will centre on a ‘strike price’, a pre-agreed unit price. When the reference price for the electricity (for intermittent generation, the day-ahead hourly market price) is below the strike price, the generator gets the reference price topped up to the strike price. However, when the reference price is above the strike price, the generator pays back the difference. The goal is to ensure a stable price for the generator. This adoption of a more stable price regime can be seen as a response to the criticism of the RO, i.e. the possibility of windfall payments when energy prices are high and the general lack of certainty it engendered, but it is not yet clear whether the CfD will offer any substantial advantage over the Feed-in Tariff mechanism employed to support RES-E elsewhere in the EU and which is regarded as being largely successful in doing so [29,45,46]. Furthermore, there is concern that the prices smaller independent generators will be a able to negotiate with suppliers for the lifetime Power Purchase Agreements (PPAs) necessary to secure project finance will be so heavily discounted as to render many projects financially non-viable. As the delivery of the UK's renewable target is heavily dependent on smaller independent renewable projects, as well as those developed by the major vertically integrated utilities, the particular difficulties faced by smaller players in achieving reference prices will need to be taken into account in finalising the CfD arrangements [47].

2.6.2. Carbon floor price

The EMR as currently proposed includes the adoption of a carbon price floor (CPF) [48]. This is a response to the problems that have undermined carbon pricing since the introduction of the EU Emissions Trading System, wherein price volatility has undermined the value of carbon and increased the uncertainty associated with investment in low-carbon technology. The measure is planned for introduction from April 2013; the expected impact of this will be to provide additional financial benefits to renewable energy and other low-carbon technologies relative to other energy technologies, with a resulting increase in their uptake. The CPF was announced in the 2011 Budget and the intention is that it will start at around £15.70/tCO_2 on its introduction in 2013 and rise following a straight line to £30/tCO_2 by 2020, then continue rising to £70/tCO_2 in 2030 (all figures are 2009 prices) [9].

2.6.3. Emissions Performance Standard

The 2011 EMR White Paper announced that the government intends to apply an Emissions Performance Standard (EPS) of 450 g CO_2/kWh to any new generating capacity. This would effectively mean that any future coal power station would have to integrate a working Carbon Capture and Storage (CCS) system. This represents a substantial shift in policy from a requirement for new coal power stations to be ‘CCS ready’. It is notable that the UK's programme for innovation in the field of CCS is currently struggling, with all utilities having withdrawn from projects to access the £1bn of public funding made available to support large-scale projects. Exemptions to the EPS limit will apply to any new coal plant taking part in UK or EU CCS research projects. The application of the policy as currently stated could limit the approval of new coal plants, providing a further driver for renewables to fill the generation shortfall.

The government states that the EPS is also intended to send a price signal to the markets to construct new gas capacity in the short term to address the significant drops in available capacity as coal and nuclear plants go offline [9].

2.6.4. Capacity Market

The EMR proposals announced the intended introduction of a capacity mechanism based on a prior consultation process, and a consultation on the nature of this mechanism resulted in the announcement of the intention to introduce a Capacity Market [49]. This will be a market-wide instrument which aims to contract capacity to meet times of peak demand. The aim is to provide sufficient incentive for investors to guarantee availability of capacity. The government has made it clear that this will include non-generational capacity such as demand side response and storage as well as generating capacity. Provision of demand side response would certainly be a market that could be (at this stage in theory only) facilitated by a greater emphasis on smarter technology and management of networks.

The perceived need for a capacity mechanism reflects concerns that the GB “energy-only” market design, with the recovery of investment costs dependent on infra-marginal rents alone, is unlikely to bring forward sufficient capacity given the increased price volatility and decreased utilisation likely to be experienced

by conventional plant in a progressively decarbonised electricity system. These concerns are reinforced by the failure of the current market design to adequately expose players to short-term price signals and by the absence of any significant demand-price sensitivity [23].

The market-wide mechanism favoured by DECC aims to address the capacity or resource-adequacy issue. However, as noted earlier, the continued introduction of intermittent, zero-marginal cost generation such as wind and PV will raise issues not addressed by the current EMR proposals. In future, conventional generation will be required to follow a demand profile that is "net" of renewable output and far more volatile and unpredictable than the demand profiles that conventional generation is currently required to follow. As noted by Hogan and Gottstein [50], this will require the future generation fleet to possess enhanced dynamic characteristics such as increased ramping ability, reduced minimum on and off times, etc., to ensure that the electricity system can continue to be operated cost-effectively and that curtailment of renewable output can be minimised. It will be important therefore that mechanisms deployed to ensure sufficient investment in generation are also capable of ensuring that the "right" type of generation is built.

There will also be a need to ensure that the capacity mechanism introduced by Great Britain via the EMR is consistent with the development of an integrated European electricity market by 2014. Market integration is to be achieved through, inter alia, the coupling of Member State power exchanges at the day-ahead and intra-day timeframes, and successful integration will be dependent on a consistent approach to setting wholesale energy prices. Different approaches to supporting capacity can impact energy prices, particularly when capacity is scarce, and there is a danger that a too introspective approach to capacity market design by Member States could distort cross-border trading.

The need to adopt a more co-ordinated approach to capacity market design within Europe and to recognise the need for increased plant flexibility has been noted by the European Commission in a recent Internal Energy Market (IEM) communication [51]. The House of Commons Energy and Climate Change Committee raised similar concerns about the EMR proposals in their scrutiny of the UK Government's draft Energy Bill [52], noting the apparent incompatibility with European market integration and failure to address the issue of flexibility.

2.7. Smart meter roll-out

The adoption of a programme to roll out smart meters to replace all current electricity and gas meters is the most significant concrete policy initiative relating to the development of smarter grids in the UK. The smart meter roll-out as currently intended should bring the UK into compliance with the European Electricity Directive which commits EU Member States to achieving deployment of smart meters to 80% of consumers by 2020 [9]. The UK Government projects a programme cost of £11.3 billion, against energy consumption savings of £18.6 billion [53]. The cost of rolling out smart meters will be borne by supply companies but they will be able pass this cost on to consumers. This is controversial in terms of what the installed smart meters will be capable of and whether they will meet the needs of the DNOs.

The UK is unusual in Europe in that suppliers will be responsible for providing, installing and paying for smart meters together with the ongoing costs of data aggregation and settlement. Smart metering potentially offers benefits across the industry. However, a mismatch between costs and benefits constitutes a market failure and broken value chain, which may result in the benefits not being fully realised. The specification for smart meters is a key area that has been influenced by the supplier-led roll-out. DNOs were somewhat slower to react to the metering policy initiative, although they have responded through mechanisms such as the Smart Grid Forum. The meter specification is an area where policy may shape UK smart grid development in the short to medium term. The initial value of smart meters to retailers is in reducing meter reading costs (a 3–4% reduction in overall costs), increased demand forecasting accuracy and reduced billing queries. These require only basic meter functionality which can be provided at low cost. Suppliers have little incentive to provide (that is fund) additional functionality.

The roll-out of smart meters is in its early stages at the time of writing, with installation initially on a voluntary basis for consumers within schemes set up by utilities who wished to initiate installation early. The government expects smart meters to be the standard replacement for 'dumb' meters where replacement was due anyway from the latter half of 2012, with an accelerating schedule of installation from 2014. Completion of the programme is intended by 2019, with an expectation that installation of smart meters in larger non-domestic sites will be complete by 2014 and most domestic premises will have smart meters by 2016. It is not clear how consumers will react to widespread installation and a negative response may yield practical difficulties [53–55]. Various concerns have been raised by the UK's Public Accounts Committee (PAC) about the plans to roll out smart meters [55]. These include:

- The costs of the switch will add to energy bills but benefits such as reduced meter reading costs may not be passed on.
- That consumers may not know how to reduce costs using their smart meters and suppliers have no guidance or regulatory obligation to instruct them.
- There is no defined strategy for ensuring more vulnerable consumers enjoy the benefits of smart grids.
- Consumer attitudes to widespread adoption of smart meters may affect rates of adoption. The PAC also expressed concern that DECC should have a more robust approach to scheduling and ensure adequate responsiveness to barriers to the timely roll-out.
- The ICT installed to utilise the data from smart meters may not be sufficiently flexible to deal with the demands of future smart grid innovation, requiring further expenditure over and above the £3billion it is currently expected to cost.

The UK body for protecting consumers in energy matters, Consumer Focus (Section 1.2.5), highlighted the concerns of the PAC in January 2012 regarding ensuring savings rest with consumers rather than retailers. Concern has also been expressed that supply companies might use meter replacement as an opportunity to sell their own products. The government committed to banning this behaviour in April 2012 [56]. This debate is notable since it emphasises the potential difficulties of the move to developing smart grids. The roll-out of smart meters represents only an early step in the move to smarter energy delivery and consumption, yet already there is conflict as to how to ensure there are benefits, to whom the benefits accrue and how to ensure costs and benefits apply equitably.

The issue of data protection and privacy is also raised in the UK Government proposals, which note the data might allow insight into the lifestyle of individual consumers and thus encroach on their privacy. The government expresses a preference for a system it refers to as 'privacy by design' wherein information not specifically required to meet regulated goals (e.g. payment for supply) is private unless the consumer makes it available. It suggests regulated duties will be narrowly defined to maximise privacy. The proposal document also highlights the need for collected data to be held securely and sets out guidelines for this [53]. The Smart Grid Forum [57] notes data privacy as an issue but

has taken little action to address this so far in work streams. Ofgem [58] has acknowledged the inevitable increase in the volume of data arising in an emergent smart grid and consulted on possible future action as regards data privacy and the possible adoption of a 'privacy charter'. Ofgem notes that the UK already has in place the Data Protection Act 1998 which sets out guidance as to the treatment of consumer data and offers legal protection against abuses, upheld by the Information Commissioner's Office (ICO). The UK Government [59,60] consulted on the issue of data privacy through 2012, setting out intended policy at the end of that year.

Effective policies to drive smart grids, the creation of appropriate policy instruments and their integration into an evolving body of regulation will be a complex task and one with potential for many pitfalls [61].

3. Regulatory issues

A large number of barriers to the shift of the UK ESI to some form of smart grid arise from the UK's regulatory framework and how it has been applied to the ESI. The light touch approach to regulation led to a disconnect between applied regulation and UK Government priorities on key issues, perhaps most notably social and environmental issues relating to energy supply [62]. This has meant that wider societal concerns adopted by policymakers have been slow to translate into regulations applied to the ESI.

Ofgem's duties have evolved since privatisation but this has been a slow process and has tended to require governmental intervention on an ad hoc basis in order to change what Ofgem can legally do, either through primary legislation or through the provision of Public Service Obligations (PSOs), which typically also require legislation. The UK Government has made efforts to align Ofgem's actions with national policy goals by allowing for the provision of guidance on environmental and social goals in the Utilities Act 2000. However, a recent government review suggested the use of guidance was not effective in aligning government goals with Ofgem actions for a number of reasons [62].

The key changes that have been made to Ofgem's duties codicil their primary duties such that they must have regard for both sustainable development and security of supply, and add secondary duties for Ofgem that require the regulator to "secure a long term energy supply" and carry out its functions "having regard to effect on the environment". DECC also emphasises the need "for an enduring solution that sees Government clearly taking responsibility for setting strategic direction, providing greater certainty for market participants, communicating strategy more effectively, and so avoiding *ad hoc* interventions where possible" [62].

The government response is to introduce a 'Strategy and Policy Statement', the goal of which is to enable investment in the UK energy sector to be secured as cost effectively as possible. The strategy will do this by ensuring greater coherence between the policy priorities of the UK Government with the duties and thus actions of the regulator.

3.1. The evolution of the UK regulatory regime and smart grids

The UK privatised its electricity supply industry (ESI) in 1989/90, opening first the generation (1990) and then supply function (1992–98) to competition, with distribution and transmission also sold into the private sector and regulated to drive down prices through benchmarking and the use o the RPI-X mechanism. The UK regulator suggests that this regulation of the latter two functions have led to a 50% reduction in the costs of network provision in the UK in the period 1990–2010 [24].

Successive UK governments have supported a system of light touch regulation of energy utilities, with the government providing a list of duties through legislation and the regulator legally obliged to operate within these parameters, but with flexibility within them. The Office of Gas and Electricity Markets (Ofgem) has been the regulator since 2000 when the previously separate electricity and gas regulators were conjoined. Ofgem is governed by the Gas and Electricity Markets Authority (GEMA), which is responsible for strategy, setting of overarching policy priorities and acting as the final decision maker on price controls and enforcement of regulation. The powers of the regulator as regards the UK ESI stem from statute, most notably the Electricity Act 1989, the Utilities Act 2000, the Competition Act 1998, the Enterprise Act 2002 and the Energy Acts of 2004, 2008 and 2010. A further Energy Bill was proposed in early 2013 to move EMR forward and regulate for new nuclear capacity, amongst other goals.

The initial regulation of the privatised UK ESI was designed with the primary goal of minimising costs to the consumer, either through competition in the generation and supply functions or through regulation and incentivisation of the networks. Over time political motivations have seen greater emphasis placed on factors other than cost, including environmental considerations (most notably climate change targets), security of supply and other social considerations such fuel poverty. Ofgem has responded to some degree to government policy goals and has increasingly adopted an approach which broadens its approach to social and environmental goals, where this can be justified within the scope of its duties.

3.2. Innovation in the UK ESI

The development of smart (or smarter) grids, whatever shape they may eventually take, is rooted in innovation. Innovation in policy and regulatory ideas will be required to create the conditions for innovation of markets, networks and services and the technologies which will be needed to support them, without forcing efforts down one particular route. Baker et al. sum up many of the arguments that underlie the need for a change in the regulatory framework of the UK ESI if greater levels of innovation are to be stimulated, highlighting the need for reform across network and market regulation, in dispatch and balancing and in terms of demand response [63]. Aghaei et al. [64] point out that the less predictable nature of intermittent renewable energy sources of electricity, as well as increased potential variation in demand from technologies such as electric vehicles and heat pumps, will mean greater challenges for effective dispatch and that new approaches will be required in order to avoid addition of costs.

It is generally recognised that the approach taken to network regulation since the privatisation of the UK electricity supply industry in 1990 has provided little incentive for innovation, with the primary focus being general cost reduction [65] resulting in R&D programmes withering. In recent years however, Ofgem has acknowledged the need for greater levels of innovation across the ESI and introduced regulatory "add-ons" such as the Innovation Fund Incentive (IFI) and Low Carbon Networks Fund (LCNF) to compensate for the lack of innovation incentives in the core RPI-X network regulation. Currently, Ofgem is leading an evolution in network regulation from the RPI-X system to RIIO, which proposes an "innovation stimulus" (discussed in greater depth below), while working in partnership with the government on a new programme of Electricity Market Reform (EMR).

The rest of this section will consider the current shape of UK electricity regulation and the impacts and limitations on the delivery of smarter grid operation. It will discuss the scope of

innovation in the different elements of the ESI and the limits of the same; describe recent efforts to broaden the scope of regulated utilities to innovate their networks as well as the need to develop policy which will allow for the ESI to deliver on the wide range of challenges it faces relating to cost, the environment, security and reliability of supply and fuel scarcity.

3.3. Innovation and distribution networks

Great Britain's fourteen distribution networks, initially owned by fourteen separate companies, have been traded such that they are operated by six companies who act as distribution network operators (DNOs). The DNOs are shareholder-owned private companies but are currently very limited in the ways they may achieve revenues. There have been a number of changes to the limitations on how DNOs can earn a return but a process is currently under way that will mean the biggest changes since privatisation.

Ofgem characterises itself as technology neutral and as declining to select a particular technology to achieve a particular goal; rather it facilitates a market system which allows companies to bring their own efforts to innovation. This is fine in theory but in practice it tends to mean that DNOs favour established technologies, and the status quo is preserved. Network regulation has tended to incentivise small incremental change and has not allowed scope for changes to the system such as movement to, for example, two-way system flow of power, more active network management and smart grids. Thus the current system strongly discourages access to the long-term benefits to the consumer that might accrue from these systemic changes.

Historically, the income of a DNO has been linked to the expenditure it is allowed by the regulator to invest in its network. This has been set every five years in a distribution price control review (DPCR), the latest, DPCR5 runs from 2010–2015 and following a review (known as RPI-X@20) the current RPI-X system will be replaced with RIIO (see Section 3.6) [24]. Determination of allowed revenue is currently based on a number of 'building blocks' which take into account operational expenditure, capital expenditure, depreciation, Regulatory Asset Value (RAV) and Weighted Average Cost of Capital. See Ofgem overview for more detail of this arrangement [66].

The model for actual calculation is complex but Ofgem has provided a visual guide to the basic concepts which underlie the calculations, see Fig. 3.

RPI-X is a price cap approach to regulation which limits price increases to the rate of inflation (Retail Price Index) minus a value *X* – in simple terms, the higher the value of *X*, the more efficiency gains the DNO has to make before they can see a return. The value of *X* is determined every five years in the current UK DPCR system and reflects productivity gains as well as proving incentives for further productivity gains by incentivising DNOs to bring down costs in order to provide a return. This price cap is devised for each year of the price review and turned into a Distribution Use of System (DUoS) charge for different customers and voltages. DNO revenue is based on what expenditure the regulator allows them to pass on to consumers, thus creating a distinction between allowable and non-allowable expenditure. DNOs avoid expenditure not likely to be allowed since it has no way to recoup these funds. Changing what is and is not allowed modifies the incentives for the DNO and thus its behaviour. The degree to which incentives have been changed for DNOs has historically been limited but this began to change with initiatives such as Registered Power Zones and the Innovation Funding Incentive, which changed further with the introduction of the LCNF, and seems likely to continue to change significantly with RIIO.

The different elements of RPI-X have expanded since being first introduced, but the underlying goal has effectively remained the same, that RPI-X would stimulate improved efficiency in network operation and thus achieve cost reduction to be passed to the consumer. Setting *X* such that companies only remain profitable by improving efficiency continuously means prices are continually pushed down.

DNOs have to comply with a number of performance measurements or are penalised. Once these are met, DNOs motivations revert to the fundamental economic drivers of the price control in order to maximise their return. DNOs thus have a number of key incentives and management drivers which shape their behaviour [67]:

1. A focus on capital asset expenditure since this will expand the Regulatory Asset Value (RAV) of the DNO.
2. An incentive to minimise operational expenditure. This incentive is significant here since it will tend to undermine substantial innovation, and confine DNO behaviour to small changes within the existing system rather than offer any potential for overall system change. This also means any activities heavily weighted towards operational expenditure are disincentivised.
3. RPI-X regulation, which is a blunt instrument to reduce costs rather than to provide incentives to meet performance standards.

3.4. Innovation and transmission

Transmission systems are generally considered to be relatively "smart" and more amenable to innovation than distribution networks. The contribution of connected generation to transmission system security, the need to accommodate varying and multi-directional power flows and the need to balance energy on a continuous basis require more sophisticated protection, monitoring, supervision and management systems than distribution systems. However, there is evidence [68] to suggest that further innovation in the operation of transmission systems would be beneficial in terms of overall efficiency, and indeed necessary if

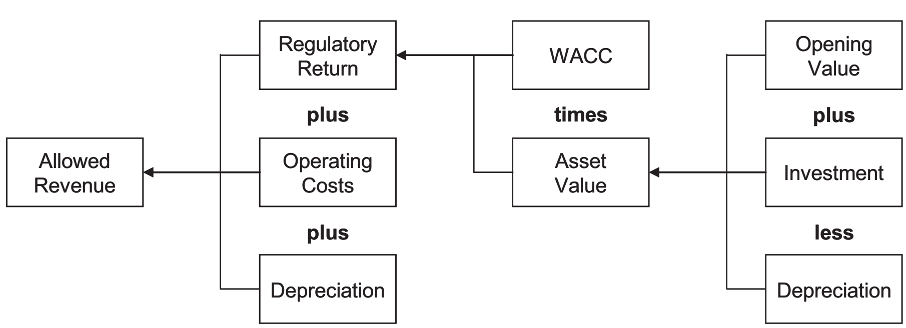

Fig. 3. Stylised Building Block Representation of RPI-X [66].

electricity system decarbonisation system is to proceed in the most cost-effective fashion. As with distribution systems however, the extent and rate with which innovation proceeds will depend on how transmission assets and operation are regulated.

The transmission network in Great Britain currently has three major Transmission Owners (TOs). National Grid Electricity Transmission (NGET) owns transmission assets in England & Wales, with Scottish Power Transmission (SPTL) and Scottish Hydro-Electric Transmission (SHETL) owning transmission assets in the south and north of Scotland, respectively. Additional smaller TOs will be created over time as with the deployment of transmission assets offshore.

The three major TOs are monopolies and have been subject to the same RPI-X style regulation described in the previous section. As with the DNO's, RPI-X regulation is being replaced for the current price control review with RIIO-T1, which places more emphasis on outcomes in determining a specific revenue stream for each TO and will run for eight years from 2013.

3.4.1. Innovation and TO incentives

Given the rapidly increasing need for investment in the transmission network both to accommodate new low-carbon generation technologies and to replace transmission assets that are nearing the end of their economic lives, there is a need to ensure that the utilisation of existing assets, and new assets as they come on line, is maximised. Baker et al. [69] point out that, typically, the utilisation of transmission networks is low at around 30% and, with a business as usual approach, transmission utilisation can be expected to decline further as networks expand to accommodate the growth in intermittent generation capacity [70]. It is important therefore that network regulation encourages TOs to objectively compare traditional forms of transmission investment with “smarter” alternatives, such as FACTS[2] network control devices or revised design and operational procedures[3] that are consistent with the very different characteristics of low-carbon generation technologies now being connected to the transmission system.

This need to move away from the tendency of existing regulation to favour traditional “asset heavy” rather than “smart” or innovative solutions is raised by Baker et al. [63], who call for the equalisation of incentives for capital and non-capital external (the costs incurred in managing the operation of the transmission system) expenditure. While not outlining detailed regulatory arrangements, they suggest that allowing TOs to retain some proportion of the savings accrued by not investing over the longer term, or else including the costs incurred in deploying smart or innovative solutions in the RAB as with traditional investment, would encourage a more objective comparison of traditional and “smart” solutions.

3.4.2. Innovation and the System Operator incentives

Notwithstanding the diversity in asset ownership, all transmission in Great Britain, including offshore assets, is operated by National Grid as the National Electricity Transmission System Operator (NETSO). In carrying out its role, National Grid operates under a System Operator (SO) incentive scheme, which is designed to ensure that the transmission system is operated in an efficient and economic manner. The SO incentive scheme establishes cost targets that NGET is expected to achieve in carrying out its operational role and has, to date, been reviewed on an annual basis. If actual costs exceed target, NGET faces a financial penalty while, if actual costs fall below target, NGET receives an incentive payment. The size of the payment or penalty is limited by a collar and cap, respectively.

While the SO incentive scheme encourages NGET to make short-term operational cost savings in an attempt to “beat” the cost targets set by Ofgem, there is little incentive to embark on innovation that would ensure cost savings over the longer term [71]. Operational savings are effectively “given up” at the end of the (to date annual) incentive period and it would not make commercial sense for National Grid to take action that would undermine the case for investment opportunities on which it could make a return via its transmission price control in order to accrue temporary short-term savings.

3.5. Stimulating network innovation

Ofgem has begun to take action to address the problem of innovation on the networks. The regulator introduced the Innovation Funding Incentive (IFI), Registered Power Zones (RPZ) in 2005 and more recently the Low Carbon Networks Fund (LCNF) has begun to be brought into use. Each programme has been introduced with the intention of opening up the scope of the distribution networks.

3.5.1. Registered Power Zones and the Innovation Funding Incentive

Both IFI and RPZ were initially proposed by Ofgem in March 2002 and then introduced as part of DPCR4 from 2005. Both are intended to “apply technical innovation in the way they pursue investment in and operation of their networks” [72]. Power Zones were “envisaged to be a defined electrical, or perhaps geographic, area that is proposed by the DNO and forms a ‘bounded network’. Within a power zone, a DNO could apply new technologies, technical solutions and operating practices, as well as pilot new commercial structures to exploit the possibilities for DG to improve quality of supply, reduce losses, minimise constraints to generator operation, and ultimately enable the network to be run at a lower overall cost. Power zones could also provide a framework in which Ofgem could encourage, in a controlled manner, DNO initiatives in relation to distributed generation by specific regulatory treatment such as appropriate treatment of costs that are incurred and other incentives.” The focus of RPZs was at the point of connection between a generator and the distribution network, with the aim of providing innovative solutions which would benefit both the generator and, in the long term, the consumer through greater competition and potentially reduced costs. DNOs were incentivised to take part in the RPZ programme via an incentive of £3/kW/year and an addition to their allowed revenue of up to £0.5 m per year. At the end of 2008–9, three DNOs were operating one RPZ project each [73]. The RPZs were superseded by the LCNF from 2010.

The IFI represented Ofgem's response to the consistent decline in investment in research and development by DNOs (approaching zero) from 1990 onwards. It allows a DNO to pass costs of eligible IFI projects to customers (declining from 90% to 70% from 2005 to 2010). Ofgem agreed in February 2006 to extend the IFI scheme to the end of DPCR5 (2015) with the aim of giving the DNOs the confidence to build their Research and Development portfolios. Eligible IFI projects are defined as those “designed to enhance the technical development of distribution networks and can embrace asset management from design through to construction, commissioning, operation, maintenance and decommissioning” [73].

The introduction of RPZ and IFI can be regarded as the first significant step taken by Ofgem in acknowledging and responding

[2] FACTS; flexible ac transmission system devices such as solid state series compensation or phase shifting devices that can control circuit flows and increase overall system utilisation.

[3] Adopting cost-benefit, risk-based, procedures that balance operational, unsupplied energy and investment costs have the potential to significantly increase system utilisation.

to the need for the regulatory framework for networks to change to the coming realities of an ESI with greater levels of distributed generation, potentially higher levels of intermittent generation and as potential forerunners to the adoption of greater levels of smart metering and other smart energy technology and demand response. Ofgem recognised that the level of risk associated with innovation regarding distribution networks did not fit with the profile of investment typified by the sector. The regulator aimed to offer the opportunity for the DNOs to secure greater reward against the risk inherent in greater levels of research, development and innovation. The eventual aim was that lessons learned under both programmes could be rolled out more widely across the network [72].

Ofgem records the total new present value of IFI portfolios for the DNOs at £67 m at the end of 2008–9, suggesting they have had value in advancing R&D expenditure [73].

It can be seen as an initial response to the need to incentivise efficient management of renewal and expansion of network assets and to enable wider provision of DG connectivity across multiple distribution voltage levels.

3.5.2. The Low Carbon Networks Fund

The Low Carbon Networks Fund (LCNF) was introduced in 2010 as part of DPCR5. The goal is to further support DNOs in investigating and deepening their knowledge and experience in the operation of networks as they evolve to take into account changes relating to security of supply and reduced carbon emissions [23].

The LCNF supports two tiers of projects: smaller projects in Tier 1 and larger ‘flagship’ projects in Tier 2. Tier 1 projects should last no longer than three years and must involve the trialling on the distribution system of at least one of the following [74]:

- A specific piece of new (i.e. unproven in GB) equipment (including control and communications systems and software) that has a Direct Impact on the Distribution System.
- A novel arrangement or application of existing Distribution System equipment (including control and communications systems and software).
- A novel operational practice directly related to the operation of the Distribution System, or
- A novel commercial arrangement with a Distribution System User.

To qualify, a project must also accelerate the move to a low-carbon economy, have the potential to offer financial benefits to consumers, directly impact the DNO's operations, generate new knowledge which can be disseminated amongst the other DNOs, and apply methods which are at the trial stage and which do not duplicate previous work [74].

Tier 2 projects are larger though subject to many of the same criteria. DNOs are limited to two Tier 2 projects each and all are subject to approval via a screening process and then evaluation by an expert panel. Ofgem states a wish to see greater flexibility in tier 2 projects. They see second Tier Projects as providing an opportunity for DNOs to engage with stakeholders including generators, consumers, supply companies to explore the interactions required with them to facilitate the transition to a low-carbon economy [74].

It should be noted that Ofgem does not hold funding for the projects; rather, approved expenditure is on an allowed basis and expenditure can be passed on to consumers. DNOs are expected to provide at least 10% of project funds themselves.

The LCNF has so far led to the establishment of a number of projects including the use of data from smart meters, the use of energy storage and the impacts of electric car usage on the network. Many of these projects can be regarded as likely to provide outputs which will assist in understanding the challenges of moving to greater adoption of smart grids.

3.5.3. Low Carbon Investment Fund

The Low Carbon Investment Fund (LCIF) is operated by DECC and provides grants to push low-carbon technologies forward with the aim of eventual commercial exploitation. The LCIF Smart Grid Demonstration Capital Grant Programme is an element of the LCIF aiming to facilitate the development of technologies relevant to the supply chains of smart grid development [75]. Grants up to £6 m were made available though only £2.8 m was taken up. Grants were available up to 25% of the total capital cost, with uplifts for collaboration and for small and medium sized enterprises.

3.6. RIIO: Revenue = incentives + innovation + outputs

The instruments noted above are essentially concerned with stimulating R&D, and while they might be seen as natural precursors to change, the shift to RIIO from 2015 represents a much bigger step towards changing the fundamentals of how the networks are incentivised and thus operate. Ofgem carried out substantial consultation leading it to make the following conclusions concerning the replacement for the RPI-X system and have a number of key features, as follows [76,77]:

- Outputs led, making it clear to networks operators what would be expected in terms of delivering safe and reliable services, on a non-discriminatory and with timely connection and access terms, customer satisfaction, limited impact on the environment and delivery of social obligations.
- Ex-ante control: an upfront price control, incorporating a return on the regulatory asset value and inflation indexation. The Retail Price index (RPI) will be retained as the inflation index, though a switch to the Consumer Price Index (CPI) will be further considered at any later price controls for gas and electricity transmission and distribution.
- An initial eight-year price control, with this extended period to be reconsidered in each price control review. A mechanism to deal with uncertainty will be available to assist with the raising of network financing where this is appropriate.
- Ofgem will adopt a transparent and proportionate approach to assessing the price control package, with the intensity and timescale of assessment reflecting the quality of an individual company's business plan and its record for efficient output delivery. A shortened price control process is possible.
- Ofgem may require market testing of proposals prior to approval of business plans. They may also involve third parties in financing major projects as appropriate.
- Ofgem will publish clear and transparent guidance as to the application of penalties to companies which consistently do not deliver on their commitments. Incentives will be “transparent, upfront, symmetric efficiency incentive rates for under- and overspend. Incentives will be calibrated to ensure they provide long-term value for money.”
- Ofgem will publish principles for setting a WACC-based allowable return which reflects long-term cash flow risk for a business.
- Ofgem will institute a time-limited innovation stimulus package which will be open to network operators and other companies to support network innovation projects. This package will include substantial rewards for companies that “successfully implement new commercial and charging arrangements”. This will consist of

three measures: Network innovation Competition (NIC), the Network Innovation Allowance (NIA) and the Innovation Roll-Out Mechanism (IRM).

Ofgem believes that this structure will allow clear incentives for the achievement of the goals of an environmentally sustainable energy sector without imposing an excessive cost burden on the consumers. It has included scope for changes should it become apparent that the model is not delivering on the desired goals. Müller characterises the shift to RIIO as a pioneering move away from efficiency incentives and towards a "holistic innovation and output-oriented approach with a forward looking, long-term value for money perspective", and offering the potential to regulatory stimulation of a more dynamic approach to incentivising decarbonisation across the supply framework. The long-term perspective is particularly praised, while raising concerns about the high level of regulatory planning and oversight inherent in the model [78].

RIIO is an ambitious though complex new model and a significant attempt to engage with the changing political and social agenda linked to energy. It is untested however, perhaps most notably as to how the network operators will respond to their new incentives and how flexible these will be in response to network operator and investor behaviour which will not provide the desired outcomes. Further to this, stakeholders have suggested there is significant concern as to the extent of innovation that Ofgem will allow from DNOs [79]. There is considerable concern over the potential for Ofgem to revert to its historical perspective and to limit the activities of the DNOs after they submit their business models under the first RIIO DPCR. There is also considerable potential for the DNOs to elect to submit proposals which do not include significant change from the status quo, which may lead to action from Ofgem if there is concern about the lack of innovation up to 2023. The DNOs will have a potentially significant possible incentive to meet goals available. Should a network operator submit a forward plan of sufficient quality, then it can be fast tracked under the 'Initial Proposals' with the possibility of early settlement of price control. Fast tracking is a strong financial incentive for network operators as it reduces time spent on managing the DPCR; this incentive to more efficient management may drive DNOs to be more innovative, which might include greater use of smart technology. Fast tracking has already been approved for the two Scottish transmission companies under the RIIO-T1 price control review. It has been noted that there is some risk of a bad solution being fast tracked [27,79].

Ofgem has made it clear that the IFI and LCNF initiatives will be rolled into and continue under RIIO. RIIO will also build additional programmes to stimulate innovation; these will include the Network Innovation Competition and the Innovation Allowance [80].

3.6.1. Network Innovation Competition (NIC)

The introduction of the NIC with RIIO-T1 and GD1 from April 2013 is intended to build on the work of the LCNF. The current LCNF will be folded into a new NIC to provide a direct equivalent for innovation in electricity distribution networks as well as transmission networks from the end of the current DPCR period in 2015. The NIC will borrow much of the process of the LCNF in terms of assessment of project potential.

The NIC is essentially a competition to encourage innovation; £240 million will be made available for innovation on the electricity transmission networks over the eight-year period of the price control review, and up to 90% of funding may be claimed. Currently the NIC will allow non-network companies to collaborate with network companies to receive funding, though the introduction of an 'innovation licence' which would allow independent work by non-network companies has been rejected [81].

3.6.2. Innovation Allowance (IA)

The IA is a development of the IFI and is intended to stimulate network innovation at the smaller scale. It will apply from 2013 for the electricity transmission network and then be wrapped into the distribution price control review from 2015. As with the IFI, spending would be capped to a small fraction of network operator revenue, with 0.5% and 1% of allowed revenues as the current proposal – a sliding scale will apply to different network operators. Ofgem has also proposed a 'sliding cap' on the amount of funding per project, dependent on the size of the project; this will vary between 5% and 10% [77].

3.6.3. Innovation Roll-Out Mechanism (IRM)

The IRM is a price control revenue adjusting mechanism intended to ensure that valuable innovation with the potential to benefit consumers can be introduced promptly. The ability to adjust revenues within a price control period to cover roll-out costs should remove or reduce the risk of network companies delaying introduction into the subsequent price control period in order to be able to include the technology costs in their business plans.

3.7. Regulated access to data

Access to data from meters for most domestic and some non-domestic consumers will be mediated through a regulated 'Data and Communication Company' (DCC) [82]. The DCC function will provide a two-way communications channel between smart meters and a central communications hub to which smart meter data users (energy suppliers, network companies and other authorised third parties) will have access in line with legislation and regulation. The DCC will be a licensed entity responsible for the procurement and contract management of service providers providing data and communications services and will be required to be independent of these providers. Award of the licence to operate the DCC is currently out to tender, with an expectation of an announcement in summer 2013. The licence holder will be subject to oversight by Ofgem and will be subject to the Smart Energy Code (SEC) [77,82–85]. The availability and quality of data will be central to the services which might be available on a future smart grid. UK DNOs have argued for 'dual port' on the meters, one port to DCC, and a port for local use and data extraction on the basis that data can easily become useless if location data is removed.

It is hoped by stakeholders that the DCC will take action in ensuring harmony in terms of the behaviours of suppliers and DNOs but also potential new market entrants, allowing the easiest possible data collection from smart meters/consumers, but also allowing other actions within the scope of what is allowed by the regulator. The ability of the DCC to pass data and/or information (the difference lies with the aggregation of the data to take away locational and other usage signals) will lie with the UK government and regulator. The capacity for how the DCC and its data management might support trading in the future has not been developed as yet but stakeholders have raised a number of concerns about the quality of the data/information they will be able to access. Equally, consumer rights groups have highlighted the need to ensure consumers are meaningfully protected.

Consumers will be obliged to make available only data relevant to billing. They will have access to at least 13 months of data concerning their own consumption, via their smart meters, and may have considerable quality of data concerning their consumption and will be able to view their own data via a computer. Should they choose to do so, they will be able to make their data available to supply companies and third parties, such as websites which

compare prices and recommend switching between companies. Suppliers or third parties will be required to have consent to access this data. Some concern has been expressed as to whether some third parties may be able to circumvent these obligations. DNOs will be “able to access domestic customers energy consumption data for regulated purposes” but only on condition that the data is aggregated such that the consumer is not identifiable and only with permission from the regulator. This approach to privacy is likely to mean that the extent to which consumers are willing to make their data available to interested parties, as well as the quality of data collected by the smart meters, will be a strong determinant in the usefulness of smart meters as network sensors. DECC had considered a position where consumers could agree to make a single agreement as to the quality of data to be made available, but Ofgem objected to this on the grounds that it was likely to become the default. The level of information available in any smart metering system will inform the level of innovation that DNOs and energy service providers can bring to the grid and thus the behavioural response within the context of this privacy policy will substantially inform the ongoing smartness of this element of energy delivery. The focus on data protection that looks likely to be adopted in the UK may be fairly restrictive, but it is entirely possible that consumer defaults on data will allow suppliers to offer new services while DNOs have only limited data for network management [60].

4. Possible implications of policy in development

The policy and regulatory landscape of energy delivery and thus of smart grids is dynamic. Even in the short term, some of the policy implementation is unclear; thus practical outcomes are uncertain. We summarise several issues which may be of importance and highlight some salient features as they relate to policy that is under development at the time of writing.

4.1. Dispatch and balancing

The current GB market for electricity, with its mechanism for bilateral trading between generators and suppliers, does not attempt to optimise for dispatch. Rather, final contractual positions are notified to the system operator at closure of the electricity market (one hour before the end of each trading period), who must then ensure a final energy balancing and that any physical network constraints are observed by buying and selling energy via the balancing mechanism. Baker et al. [63] note significant potential for lack of optimisation stemming from this arrangement due to internal trading between companies with trading and generation arms and the need for individual companies to cover their own imbalance risks, rather than the “aggregate” system-wide risk seen by the system operator. They note that the resulting system inefficiencies possibly amount to an increase of around 3–4% in additional fuel cost compared with that which would be incurred with a system of “central dispatch” by the system operator.

There is also concern that the disaggregated market arrangements that exist in GB and most of Europe may be less suited to a low-carbon electricity system than the “pool” type markets that exist in parts of the US and elsewhere. The deployment of large amounts of intermittent renewable generation will increase the requirement for MW reserves and cause its utilisation to become more volatile. High levels of reserve will need to be scheduled when wind or other intermittent renewable output is expected to be high, while less reserve will be required when intermittent renewable output is forecast to be low. Baker et al. note that market arrangements that allow energy and reserve requirements to be optimised together, as is the case with the US electricity pools such as PJM, are likely to be superior to market arrangements where energy and reserve requirements are dealt with separately, as is the case in GB and most of Europe.

Much of the increased reserve requirement necessary to accommodate an electricity market dominated by wind and other intermittent renewable sources such as solar will need to be provided by conventional plant, operating at part-load. As noted in Section 2.6.4, conventional plant will therefore need to be far more flexible in order to meet a volatile demand profile that is “net” of intermittent renewable output. The development of intraday energy trading platforms as foreseen by the integration of European electricity markets will allow some of this “volatility” to be traded out as real time is approached. However, as suggested above, the simultaneous optimisation of energy and reserve and 5 min re-dispatch capability of the pool-type markets seen in the US seem intuitively more suited to a generation portfolio dominated by intermittent generation. Smart grids will also have a role to play in dealing with intermittency, through demand response and the development of “virtual” generation projects that can respond flexibly to system needs and provide services that would otherwise need to be provided by conventional generation.

4.2. Consumer issues

Many of the changes that smart grids and attendant technologies will imply will impact consumers. These may include – with different levels of likelihood – the following:

- the introduction of smart meters into consumer property may occur with different levels of information,
- the transmission of data and the ownership of that data by private partners, and
- greater levels of demand responsiveness, with different levels of automation of consumer usage. There is considerable potential for variance in accessing different tariff rates, for example relating to a consumer's position on the grid and the ‘shiftability’ of their demand. There is considerable potential for increased complexity.

These will have potentially significant implications for consumers relating to privacy and data protection, access to pricing and may impact more negatively some consumers than others, most notably the more vulnerable energy consumers.

It is difficult to gauge the extent to which consumer representation can influence policy concerning smarter energy delivery. The absence of a consumer representative on the SGF is not a positive sign. The regulator's legislated focus on the economics of energy delivery will continue to play a role in offering some protection, but the broken value chain (Section 2.7) may prove to be an inherent difficulty to the UK ESI framework. This might complicate Ofgem's ability to maximise value for the consumer if it is not addressed, preferably within the context of greater government coordination of delivering a smarter energy system.

A document published by DECC/Ofgem has suggested that value chain savings to consumers could be in the order of £2–£4billion by 2050, though it has credited the figure to another agency in its overarching Smart Grid policy document [12,6,86].

SmartGrid GB suggests three key recommendations for the industry relating to UK consumers and smart grids [87]:

1. to assess the likely potential for SG improvements that require consumer action against those that do not.
2. to model a whole SG system to improve overall understanding.
3. a coordinated programme to improve consumer education and awareness of smart grid potential and its possible value to them.

4.3. Smart metering and the DNO

UK DNOs perceive the benefits of smart meters for active network management. However, under the UK's supplier-led roll-out DNOs will make no contribution to the costs of smart metering and therefore have difficulty in making their case for more advanced functionality. These additional functions might improve system reliability and help limit price increases linked to the challenges arising from future low-carbon policies or the need for network reinforcement. Additional functionality might allow benefits such as time-of-day and dynamic pricing, which might mean further benefits to suppliers in terms of demand shifting and energy imbalance management. At a system level, this ability to more accurately forecast demand, manage imbalances and shift demand away from peak periods will bring general benefits in terms of reduced generation capacity requirements, increased operational efficiency and an overall reduction in carbon emissions [63,88].

As currently devised, cyber security management will be fragmented, with responsibility split across different parts of the electricity networks companies. An integrated approach is likely to be required, redefining boundaries at the interfaces between National Grid and the DNOs. Initial work by DECC and Ofgem through the Smart Grid Forum [57] suggests that maintaining cyber security will require an evolving approach that accounts for the changing nature of the smart grid and legacy systems. Relatively little work has been done on enabling these as elements of strategic policy however.

There is a perception amongst some stakeholders that systems might have to be replaced in the medium term if new technology or applications come to market requiring greater bandwidth or improved bandwidth solutions. It was suggested much will depend on the flexibility that gets defined into the communications hub for smart meters initially and the scope of what this might be able to deal with as the sector develops. The Smart Grid Forum's Work Stream 4, titled 'Closing Doors', will address issues such as these, considering the cross-cutting issues arising from some adoption of some policies adopted in the short term and their wider consequences.

4.4. Market design

The roll-out of smart meters will provide a platform for potentially transforming how energy markets operate in the transition to a low-carbon electricity system. Customers may be able to benefit from innovative products, better service, lower costs, and more effective competition. Smart meters would be essential in terms of facilitating consumer involvement in the electricity market to ensure that the costs of transitioning to a low-carbon electricity system are minimised. [25].

Ofgem has embarked on a work programme – Smarter Energy Markets (SEM) – to deliver complementary electricity market reform (Section 2.6) with the objective to improve competition and consumer protection [26]. The most significant development may be in the market environment that supports the system-wide development of demand side response (DSR) and innovative products. Such new energy services and time-of-use tariffs may encourage the efficient use of energy and reduce customer costs. However, if the potential of smarter metering and increased consumer participation is to be fully realised, the SEM programme will need to address the inherent disadvantages that small independent generators, suppliers and aggregators face in participating in market arrangements. For example, the need to establish a continuous 24 h energy trading capability and meet the credit conditions set by established trading platforms in the UK may place a disproportionate burden on smaller generators and suppliers. One particular issue related to DSR that will need to be addressed by the SEM programme is the potential conflict between its use for energy balancing and network constraint alleviation [89]. DSR has the potential to deliver significant system level cost benefits through reduced capacity and generation reserve requirements. Additionally, network-level benefits will come from avoided transmission and distribution investment costs. However, there will often be competition between the two roles and a market mechanism will need to be developed that can identify the relative value of various applications and allocate available resource accordingly – taking into account locational issues.

Baker et al. [63] emphasise that the infrastructure of the UK ESI and the way that the electricity market is constructed have been based around centralised generation. The mechanisms for physical delivery are rooted in the use of large-scale, highly controllable plant with high levels of availability. The transmission network was designed to be capable of delivering the output of all generating capacity and thus had few constraints. The pre-privatisation ESI had a high capacity margin which has been whittled away as demand rises and plants become obsolete. New plant has been economically difficult to develop. The design of the market for trading in electricity means system congestion costs have been socialised while long-term investment costs in the transmission network have been largely predictable and determined on an ex-ante basis with a focus on improving spending efficiency and cost effectiveness of allowed expenditure. They suggest that an ESI requiring the low carbon emissions of the UK policy aims will need to deal with large volumes of intermittent RES-E, ultimately using fossil fuels only as the last resort. Baker et al. consider the need for a market sector to evolve to meet the needs of a low-carbon economy, highlighting for example the consequences of connecting renewable resource ahead of transmission reinforcement in order to meet renewable targets, the associated growth in congestion costs and the need for "anticipatory" investment to mitigate these costs. An incremental approach to changing from the current system is suggested and informs their consideration.

Baker et al. [63] also consider the ongoing performance and potential evolution of the current 'energy-only' market which applies within the UK ESI and the challenges that are likely to develop in light of the expected changes to that market, along with their implications for maintaining sufficient margin to meet peak demands. They note that intermittent resources such as wind will never be financially viable in a pure energy-only market and will always require additional support – even when or if they become fully competitive with conventional generation technologies. The impact of decreasing utilisation and increasingly volatile energy prices on the economics of conventional generation is also considered together with the potential need for additional support in the form of Capacity Markets, although their report predates the decision by the UK government to select this as the option for ensuring sufficient investment in generation.

The shift in market design to support a more sustainable electricity system rather than just large conventional generation that is now under way also needs to take into account the potential contribution to be made by smarter networks and demand response. Incentivising the use of smart technologies can reduce or delay the need for investment in traditional, expensive, long-lived transmission or distribution assets in an increasingly uncertain world. Similarly, the impact of demand engagement in Capacity Markets or "smarter" wholesale energy markets that encourage a more dynamic response in balancing timescales can reduce the need for investment in polluting conventional "back up" generation, in addition to reducing energy price volatility.

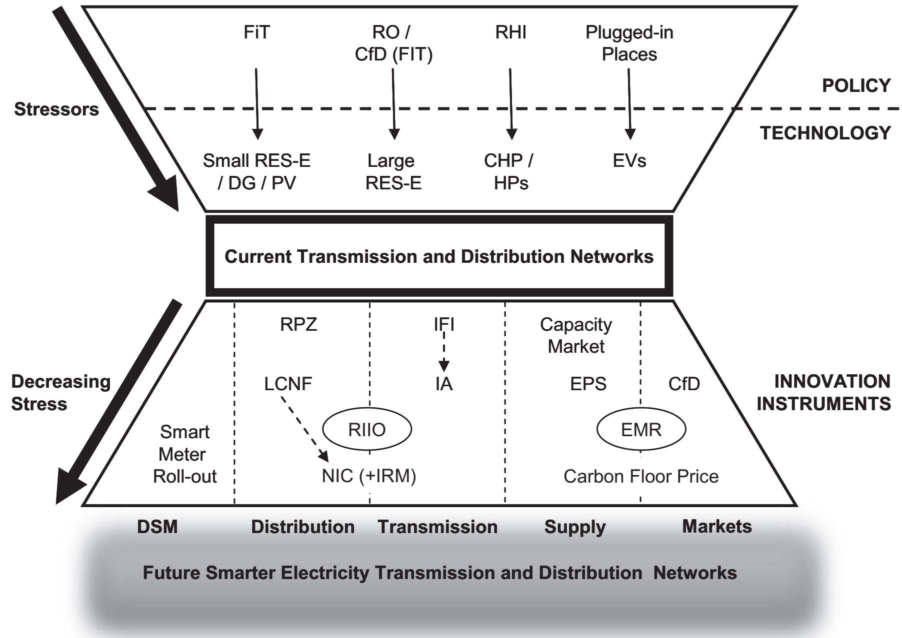

Fig. 4. Major policy instruments to stimulate innovation for the development of smart grids. (All acronyms are explained in the text) (Authors' design, 2014).

5. Conclusions

The UK is still at an early stage in terms of acting to develop a smart grid, but the same can be said of most countries. What makes the UK interesting is that it is at the stage where it is discovering and uncovering the complexities of a potential move to smart grids in a highly liberalised and competitive electricity supply industry. Through the introduction of funding mechanisms and, more recently, performance-based regulation in the form of RIIO, it is beginning to address the decline in innovation that has occurred since privatisation and realign its priorities to incentivise many of the drivers which create demand for smarter delivery, while at the same time trying to create the incentives for a system better able to accommodate them. The factors that are currently and can be expected to continue to place stress on UK electrical delivery are summed up in Fig. 4.

Parallel work to ensure that the wholesale electricity market can support the volume of low-carbon capacity necessary to deliver the UK's renewable targets and at the same time maintain security of supply will bring fundamental change. It will be necessary to ensure that these developments do not disadvantage smaller renewable projects and that some of the inherent disadvantages faced by smaller players in the current market environment are addressed. Ofgem's initiative to launch a Smarter Markets work programme will investigate the changes necessary to encourage the participation of smaller players and individual consumers in the electricity markets, which is an encouraging development in this regard.

These initiatives make the UK something of an early mover. However, the UK's preference for a supplier hub and reliance on a supplier-led rollout of smart meters means that it has introduced some additional complexities not seen elsewhere, which seem likely to outlive their initial adoption and may act to limit the speed with which smarter technologies and services can be brought into use, and their scope.

Undoubtedly, the changes to the market and regulatory structures that the UK is moving to introduce will not provide a final solution to the complex shifts that will be needed to restructure the incentivisation basis for ESI actors and stimulate the innovation which will be essential to managing the radical shifts which are core to the UK's expected shifts in generation and consumption, and the changes in management these will require. The current changes will need to be the first of many required to ensure smarter transmission and distribution grids contribute effectively to the delivery of the UK's energy policy goals. There is also an external dimension to consider, with a need to ensure that initiatives taken by the UK are consistent with the development of a single European electricity market, the broad structure of which is to be in place by 2014. However, the steps taken by the UK represent a bold change of direction in a highly liberalised national energy framework and one which shows a willingness to address the challenges that most European countries will be facing in coming decades.

The organisational structure introduced by the UK to drive the introduction of smarter networks at both the transmission and distribution level is an attempt to begin coordination of available ESI resources, identify potential barriers to deployment in advance and develop potential solutions. However, a number of stakeholders have highlighted the need for the UK Government, working in partnership with the regulator, to take an even more active role in ensuring that the process of moving to smarter energy delivery is more coordinated if problems, and unnecessary costs, are to be avoided. The SGF and ENSG are welcomed as key organisations in bringing together key stakeholders and shaping future policy, but these stakeholders, along with projections such as those made by SG-GB, also suggest that a stronger government lead and stronger systemic coordination are needed [11,79]. This will need to occur as part of a process of developing greater understanding of the implications of ongoing system changes, including application of policy instruments, evolving regulatory architecture and capturing the fullest understanding of their use.

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